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PROGRESS REPORT ON STUDIES FOR THE CONTROL OF WHITE GRUBS IN FOREST NURSERIES

By
R. A. St. George,
Associate Entomologist

Conducted by the Bureau of Entomology in Cooperation with Department of Conservation and Forestry of North Carolina and the South Carolina State Forestry Commission. April 9, 1934

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Progress Report on Studies for the Control of White Grubs in Forest Nurseries.

Introduction

As the result of extensive damage caused by the larvae of white grubs to pine seedlings, during the mid and late summer months of 1931, in State and private forest nurseries, cooperative tests were arranged between them and the Bureau of Entomology to study methods effective in the control of these insects.

Such tests have been conducted during the past two seasons principally with the State Forest Nurseries located at Clayton, N. C., and Camden, S. C., although some work has been done in cooperation with the privately-owned Statesburgh Forest Nursery, located at Sumter, S. C. The last mentioned one is not located far from the Camden nursery.

Because of limited personnel it has not been possible to make a major project of this problem. As a result tests have been conducted on a part time basis and the work of the Bureau has been largely of an advisory nature rather than otherwise.

Since a review of literature revealed that there was comparatively little information available as to the life cycle of forms found in the South, or methods of control that were applicable to nursery practice in the region, the initial plans outlining the work relating to control were largely guided by the favorable results obtained by the Japanese Beetle Laboratory in the eradication of Scarabaeid larvae by the use of soil poisons.

The Nurseries

All three nurseries are located in the Coastal Plain and, although somewhat separated, because of the nature of the soil and uniformity of practice, their problems may be regarded as being essentially the same.

The two State nurseries are located on well drained sites of several acres in extent. The soils consist of light grey sandy loams having a Ph value ranging from 5.2 to 5.6. The private nursery is located more in a bottom land and the soil is a little heavier. The land, however, has been well drained. Bordering one side of each of these nurseries is a stand of pine with occasional hardwoods.

The nursery practice is quite similar in all three places. The seeds are usually sown during February or March. Up to the present time this has been done by broadcasting. This coming season plans are being made to drill some of the seeds. The seed beds are usually partially shaded by laths during the early season. Water is supplied by an overhead sprinkling system. Because of the long growing season the seedlings attain sufficient size during the first summer to permit their removal without the necessity of transplanting while in the nursery. In fact, they develop so fast that they cannot be handled without being root pruned if left in beds the second season. A three year rotation of the beds is the usual practice although this has not invariably been followed. In some instances pine has been planted for 2-3 years in succession. Such procedure is rather unusual. Clean culture is practiced in all nurseries. Thus, the beds are periodically weeded and the paths and ground along the margins of the nursery are kept clean. In spite of such practice grub damage is severe at times.

Life History Studies

Through the work of Davis[1], Langston[2] and Luginbill[3] considerable information has been made available concerning the species of Phyllophaga occurring in the South, their host plants and flight period.

Luginbill made such information available for 22 of the 31 species of Phyllophaga which occur in the state of South Carolina. This work was done at Columbia, not far from the state nursery where a portion of the present tests are being conducted. He lists 33 different host plants for the 22 species which he studied. Adults of 7 of these species were found to feed on longleaf pine and one of them (*P. luctuosa* Horn.), in addition, feeds upon loblolly pine as well. In all 18 host plants have been recorded for this species alone.

To date adults of only 5 species (*P. impar* Davis, *P. luctuosa* Horn., *P. marginalis* Lec., *P. prununculina* Burm. and *P. micans* Kn.) have been taken in these nurseries. However, the larvae of the following 11 species are believed to be represented: *P. futilis* Lec., *P. luctuosa*

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1. 1919. Davis, J. J. Common white grubs, U.S.D.A. Farmers' Bulletin 940, 26 pp.

2. 1927. Langston, J.M. Phyllophaga of Mississippi. Tech.Bull.15, A & M College, Miss.

3. 1928. Luginbill, Phillip. The beetles of the Genus Phyllophaga inhabiting South Carolina. Ann.Ent.Soc.Am. Vol. XXI, pp. 47-91, 36 figs.

Horn. *P. ephilida* Say, *P. horni* Smith, *P. fraterna* Harris, *P. torta* Lec., *P. profunda*, *P. prunina* Lec. and *P. micans* Knoch. These forms were determined by the use of keys so admirably prepared by Hayes[4] on larvae of the Scarabaeoidea.

Various workers have suggested that in the extreme South certain species have a cycle of two years or even less.

Davis reared one form, *P. ephilida*, which is known to have a two year cycle in the South, There are probably many more of them which have a life cycle less than 3 years.

The present studies indicate that there is a considerable overlapping of generations since larvae of the same species have been found together which vary considerably in size. Further, there is some suspicion that with forms having a short cycle (2 years or less), there is a possibility of the young grubs becoming injurious during the late fall months of the first season.

Adults are in flight from the latter part of March until the middle of August with the maximum flight period of most species occurring during April (Table I). This is the case with *P. luctuosa* Horn, the form encountered most frequently so far in these studies. Two species (*P. prununculina* Burm. and *P. ephilida*) do not begin to fly until June, at which time they have their maximum flight. Five other species whose flight periods are not so well known are believed to begin their flight at about the same time.

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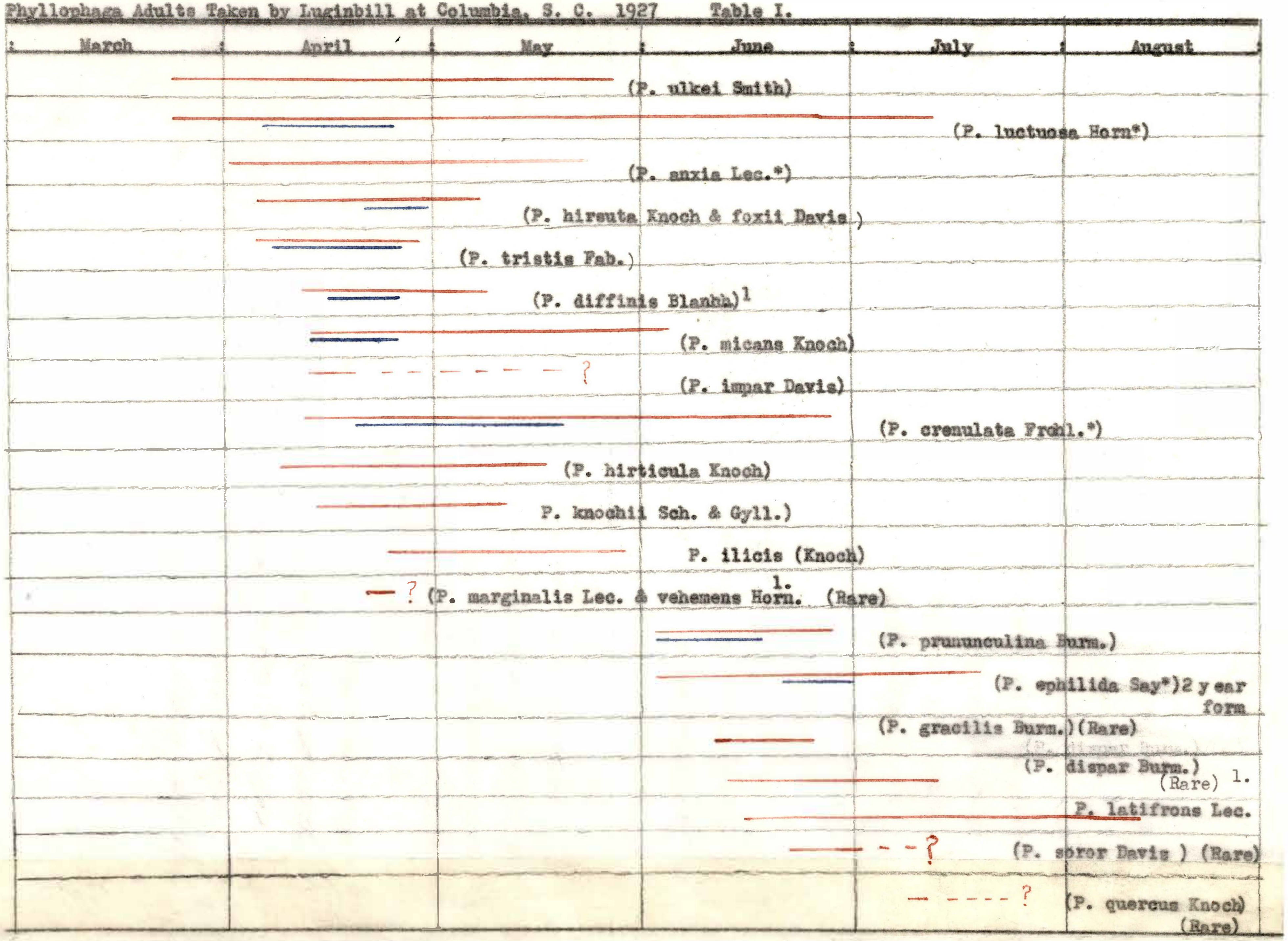
[4] 1929. Hayes, W. P. Morphology, Taxonomy, and Biology of Larval Scarabaeoidea. Ill. Biological Monographs. Vol. XII, April, 1929, No. 2, 119 pp. with 15 pl. and keys.

Phyllophaga Adults Taken by Luginbill at Columbia, S. C. 1927 Table I.



🟥 Duration of flight (Known)
🟦 Maximum
* Most common

1. All but these 3 species also taken in N. C. and mostly around Raleigh.

Usually the grubs become somewhat active by April 15. Although occasionally considerable damage is caused during early spring, most of it appears to be confined more to the late summer and fall months of certain years. Such damage is further characterized by the sporadic appearance of the grubs which appear to be able to migrate laterally for considerable distances, or penetrate the soil at various depths as seems necessary because of changes in climatic conditions or in their food supply. This is especially true following occasional showers during prolonged periods of drought. At such times the grubs come to the surface quickly and feed voraciously, causing extensive damage in a short period. Then they penetrate thebground again apparently until such time as moisture conditions become more favorable near the surface. During years of normal precipitation they stay near the surface.

Periods of heavy infestation were recorded during the months of August and September in 1931 and 1932 at the Camden and Sumter, S. C. nurseries, but at the Clayton nursery considerable injury was experienced during the spring months of the latter year. During 1933 there was comparatively little activity at any of the nurseries.

Since the nurseries used a certain amount of green manure, other species of grubs were found which are often confused with *Phyllophaga*. Principally among these was the southern green June beetle (*Cotinis nitida*). Other forms frequently encountered were *Ligyrus gibbosus* DeGeer, *Aphodius* sp., *Anomala* sp., *Gymnetis* sp. and *Euphoria sepulchralis*

Fab. None of these manure forms appeared to cause any injury to the seedlings, even when caged with them without the presence of humus.

During August 1932 the following parasites were noted to be numerous and many parasitized larvae were found: Scolia nobilitata Fabr. and Campsomeris (Trielis) octomaculata race hermione (Banks).

Control.

Since the nursery practice in these regions is not adapted to the sterilization of the soil by means of live steam preparatory to establishing the seed beds, as is the case in some localities, experiments were planned to determine the toxicity of certain chemicals to the grubs. For this work, insecticides were sought which would be effective in killing grubs in emergency periods as well as those which could be used to treat the soil at the beginning of the season when the beds were being prepared. In the latter case it was hoped that a chemical could be found that was non-toxic to the plant, cheap, easily applied and effective for a period of one or more seasons.

Remedial Measures

In order to determine what chemicals are satisfactory for emergency use, tests were conducted with carbon bisulphide undiluted and in emulsion form. The emulsion contained 50% disulphide. In addition to this chemical one of the nurseries, on their own initiative, used sodium cyanide. This chemical was not recommended by the Bureau as it was regarded as being too dangerous to plant growth.

Carbon Disulphide

Between September 9 and October 2, 1932, at Camden, S. C., carbon disulphide was applied to 20 beds containing six month old seedlings. The beds selected for experimental treatment contained 100 sq. ft. each (4' x 25') and averaged 4,000 seedlings. The following species were represented, longleaf pine (7 beds), slash (6), loblolly (4), and shortleaf (3) beds. Each species had from 3 to 5 check beds. The chemical was applied at the rate of 1 1/2 oz. per sq. yd. or 15 oz. per bed. From 6 - 8 holes, each 6" deep, were made per square yard. In the longleaf bed a little grub activity was noted subsequent to treatment but there was complete mortality in the rest. However, since the grub population was low at the time of application the results are not so significant. The loblolly and particularly the shortleaf seedlings had a slight loss over the check beds, being .2% and 1.2% respectively. Where some beds were retreated the loss increased to 1.5% and 3.3% respectively. This may have been due to several factors, but the nurseryman was of the opinion that the chemical was slightly toxic to those species where the treatment was close to the plant.

Similar tests were conducted successfully at Sumter, S. C. where the grub population was high (28 grubs per sq. ft. in a bed containing 276 sq. ft.) and no loss of seedlings was reported.

Carbon Disulphide Emulsion

Other tests in these localities were conducted to determine the toxicity of carbon disulphide emulsion to the grubs and seedlings at various strengths. The emulsion was diluted with 50 gallons of water per one, two and three quarts respectively and applied at the rate of three pints per sq. ft. of soil surface by flooding the ground. One nurseryman tried applying it by sprinkling the emulsion over the beds.

On September 9 at the Camden nursery six slash pine beds were treated by flooding the surface. For this purpose it was found that a (T) shaped tin pipe with a funnel at the top made a convenient method of applying the emulsion quickly and without danger of it coming in contact with the needles. The piece of pipe parallel to the ground was perforated with numerous holes. Five of the beds were treated with the emulsion containing one quart and one bed with two quarts of the emulsion to 50 gallons of water. Both treatments were successful but the grub population was found to be low. In the one quart beds only one grub per eight sq. ft. was found In the two quart beds they were more numerous. No living grubs were found in either bed and no further infestation occurred the remainder of the season. The growth of the seedlings was not retarded and they were not injured in any way. The check beds contained numerous living grubs.

At the Clayton Nursery the emulsion was applied at the rate of three quarts to 50 gals. of water by sprinkling it over the beds. This resulted in apparent injury to the needles, since the plants appeared to be burned and their growth stunted. The loblolly and shortleaf pines appeared to be affected more than the slash or longleaf in this respect.

Sodium Cyanide

On September 15, 1932, at the Camden nursery, a 60 ft. (240 sq. ft.) slash pine bed that was being invaded by white grubs was treated unknown to the Bureau with sodium cyanide. It was applied at the rate of one pound to 75 gallons of water by flooding the surface of the soil, taking precaution not to allow it to some in contact with either the needles or stems of the seedlings.

As the result of such treatment, not only the grubs, but also every seedling in the bed was killed.

Preventive Measures

Although it was found that carbon bisulphide emulsion could be used successfully when applied properly, there is the objection that it is not practical to use extensively on account of its expense. For this reason further experiments were undertaken to find a chemical that would be suitable when applied atbthe beginning of the season when the seed beds are prepared. Such a chemical should be affective for a period of one or more seasons.

The initial tests for this purpose were made with acid lead arsenate, since this chemical was found to be the most satisfactory one to use for the control of Scarabaeid larvae in New Jersey.

Tests with Acid Arsenate of Lead

A review of literature revealed that the Japanese beetle was readily controlled when 1,500 lbs. per acre of arsenate of lead was applied to the soil. This dosage with modifications was used as a basis for initial tests with this chemical for the control of _Phyllophaga_.

At the Camden nursery the chemical was applied in varying dosages and at different depths in order to determine whether or not it is toxic to the roots of the seedlings.

Altogether the chemical has been applied in amounts varying from 215 to 4,290 lbs. per acre (= 1/2 to 10 lbs. per 100 sq. ft. bed). Those dosages above 2,150 lbs. per acre (= 5 lbs. per 100 sq. ft.) were not suggested by the Bureau. The tests have been run for the past two seasons. No chemical has been added after the initial treatment in the spring of 1932. From time to time analyses have been run on the arsenic content of the plants. Notes were kept by the person in charge of the nursery throughout the season. Observations were mainly recorded at the time of weeding or at others when grub injury became apparent.

The 1932 Tests

The following beds were established at the Clayton nursery during the early part of April 1932 when acid arsenate of lead was applied by spading it into the soil to a depth of six inches in all cases.

(1) Shortleaf pine, 3 beds, each treated with dosages of 2, 3 and 4 lbs., and in addition, 1 bed treated with 10 lbs., per 100 sq. ft. of soil surface. Five check beds were left untreated.

(2) Loblolly pine, 3 beds each treated with dosages of 2,3 and 4 lbs. per 100 sq. ft. Six check beds were selected for comparative purposes.

(3) Slash pine, 3 beds each treated as the loblolly pine. The checks also were the same.

The results of these tests are presented in Table II. The following relations will be noted:

1. Untreated beds of shortleaf, slash and loblolly pine seedlings were subject to severe white grub injury and were somewhat susceptible in the order mentioned. The extent of such injury varied from 25.9% to 38.44% in 17 check plots (each 16 2/3 ft. sq.) The percentage of culls was about the same for shortleaf and loblolly pines but slightly less for slash. It ranged from 6.06% to 10.95%.

2. The application of arsenate of lead to seed beds by spading the poison into the soil to a depth of 6 inches, preparatory to sowing the seed, appears to result in subsequent injury to the seedlings in two ways, (1) by killing them, and (2) by stunting their growth to such an extent that it necessitates their being discarded as culls.

3. According to species, the percentage of culls is about the same, but shortleaf pine is much more susceptible to the poison than slash and loblolly, judging by the larger number of seedlings being killed from it. The percentage of seedlings affected by the combined causes, due to arsenic injury (culls and killing), is greater than the damage caused by the grubs alone; it being about twice as much for shortleaf pine and only slightly greater for the other two species. The percentage of seedlings, either killed by the poison or stunted by it (culls), does not appear to increase with dosage.

4. The application of the arsenate of lead prevented practically all grub damage to the seedlings in the various plots. A dosage of

TABLE II

INJURY TO PINE SEEDLINGS BY WHITE GRUBS AND LEAD ARSENATE

(Sample area 16.66 sq. ft. containing 799 to 1378 seedlings - Arsenic spaded to depth 6")

(Beds established April 1932, at the Clayton, N. C., Nursery. Examined February 1933)

Species	No. of beds	Dosage lbs. per 100 sq. ft.	Present Culls		Percent arsenic killed	Total % arsenic affected	Percent grub damaged[b]	Total % affected by grubs and arsenic	Percent height attained[c]	Percent good seedlings
			Normal	Arsenic affected[a]						
Shortleaf	5	Checks	9.56				38.44		100	52
	3	2	"	22.24	38.2	60.44	0.73	61.17	76.7	41.3
	3	3	"	19.14	35.0	54.14	0.00	54.14	86.5	36.3
	3	4	"	15.94	32.5	48.44	0.00	48.44	78.3	42.0
	1	10	"	20.44	36.0	56.44	0.00	56.44	106.0	34.0
Loblolly	6	Checks	10.95				25.9		100	63.15
	3	2	"	21.29	7.56	28.85	0.0	28.85	93.4	59.9
	3	3	"	31.35	0.00	31.35	0.0	31.35	83.8	57.7
	3	4	"	30.75	0.00	30.75	0.0	30.75	76.7	58.3
Slash	6	Checks	6.06				29.1		No data	64.84
	3	2	"	23.44	11.42	34.86	0.75	35.61		58.33
	3	3	"	22.84	18.20	41.04	.10	41.14		52.80
	3	4	"	22.74	20.00	42.74	3.30	46.04		47.90

Remarks: (a) Inasmuch as the number of culls in the treated beds increased steadily with the application of arsenic, it is assumed that the difference in number is due to the arsenic. The percentage of culls listed in column "Arsenic Affected" is in addition to that as noted in the check beds.

(b) Dead seedlings were pulled up at each weeding; those whose roots were cut off were classified as grub damaged. No damping off or other diseases were noted.

(c) Based on average of 100 samples taken at random in bed.

two pounds per 100 sq. ft. was as effective as larger amounts which were increased up to 10 lbs. This indicated that dosages in excess of 2 lbs. are not necessary or practicable.

5. Dosage did not appear to have much relation to height growth, since the minimum amount used affected it nearly as much as the maximum.

6. The roots of the arsenic treated seedlings were not as well developed as were the checks.

7. The above tests suggest that it will be possible to materially reduce the dosage and still be able to control the grubs. It is believed that small quantities should be employed such as 1/3, 1/2 and 1 lb. per 100 sq. ft. of soil surface. New beds should be used for this experiment.

These unfavorable results, due to the acid lead arsenate being toxic to the seedlings, were wholly unexpected, since this chemical had been used safely in treating plants in the New Jersey soils. It is quite probable from the above findings that there this difference is due to a variation in the character of the soils. Before commenting on this phase of the problem, let us review the results of tests conducted with this chemical at the other nurseries.

The following tests were established at the Camden Nursery in April 1932. The arsenic was applied at different depths in order to note the resulting effect of the chemical on root development of the seedlings. In all, 9 slash pine beds were treated. There was a check bed for every treated one. The dosages were applied at the rate per 100 sq. ft. of soil surface. They were prepared as follows:

One of each of three beds was given a dosage of 4 lbs. of arsenic and applied as follows: (1) raking it in to a depth of 3", (2) spading it in to a depth of 3", and (3) spading it in to a depth of 10".

Two beds each were treated by spading 3 1/2, 5 and 10 lbs. of the chemical into the upper 6" of soil. The average bed contained 4,000 seedlings per 100 sq. ft.

The results are summarized in Table III.

It will be noted in the above table that although the results cannot be compared directly with those of Table II, in as much as the data were not taken in the same way, yet in general, it can be seen that the arsenic apparently has caused a much greater percentage of the seedlings to die than have the grubs. This relation may have been somewhat different if the drought had not apparently kept the grubs from being active near the surface of the ground.

Regardless of insect activity, it will be noted that the plants were considerably stunted in height growth and in this respect the results are quite comparable with the same species treated at the Clayton Nursery (Table II).

Furthermore, an examination of the last column reveals that root development was retarded nearly 50 percent. The plants were further characterized by marked needle injury. They appeared as if having been burned.

TABLE III
INJURY TO PINE SEEDLINGS BY WHITE GRUBS AND LEAD ARSENATE

(Each bed 100 sq. ft. (4' x 25') and contains on an average 4,000 seedlings)

(Beds established April 4, 1932 at the Camden, S. C. Nursery. Examined)

Species	No. beds	Dosage lbs. per 100 sq. ft.	Treatment	Percent			Percent good seedlings	Percent height attained [a]	Root development: length inches
				Arsenic killed	Grub damaged	Killed other causes			
Slash	9	Checks	-	-	6.82	1.10	92.02	100.0	7.5[b]
	2	3 1/2	Spaded 6"	21.2	0.48	0.12	-	71.4	
	2	5	" "	25.3	0.09	0.12	-	58.7	
	2	10	" "	11.6	0.00	0.09	-	49.2	
	1	4	Raked 3"	11.9	0.00	0.00	-		3.0[c]
	1	4	Spaded 3"	14.4	0.00	0.00	-		3.3[c]
	1	4	" 10"	27.1	0.18	0.09	-		3.0[c]

(a) Percent height is based upon the measurement of 200 seedlings in each area treated.

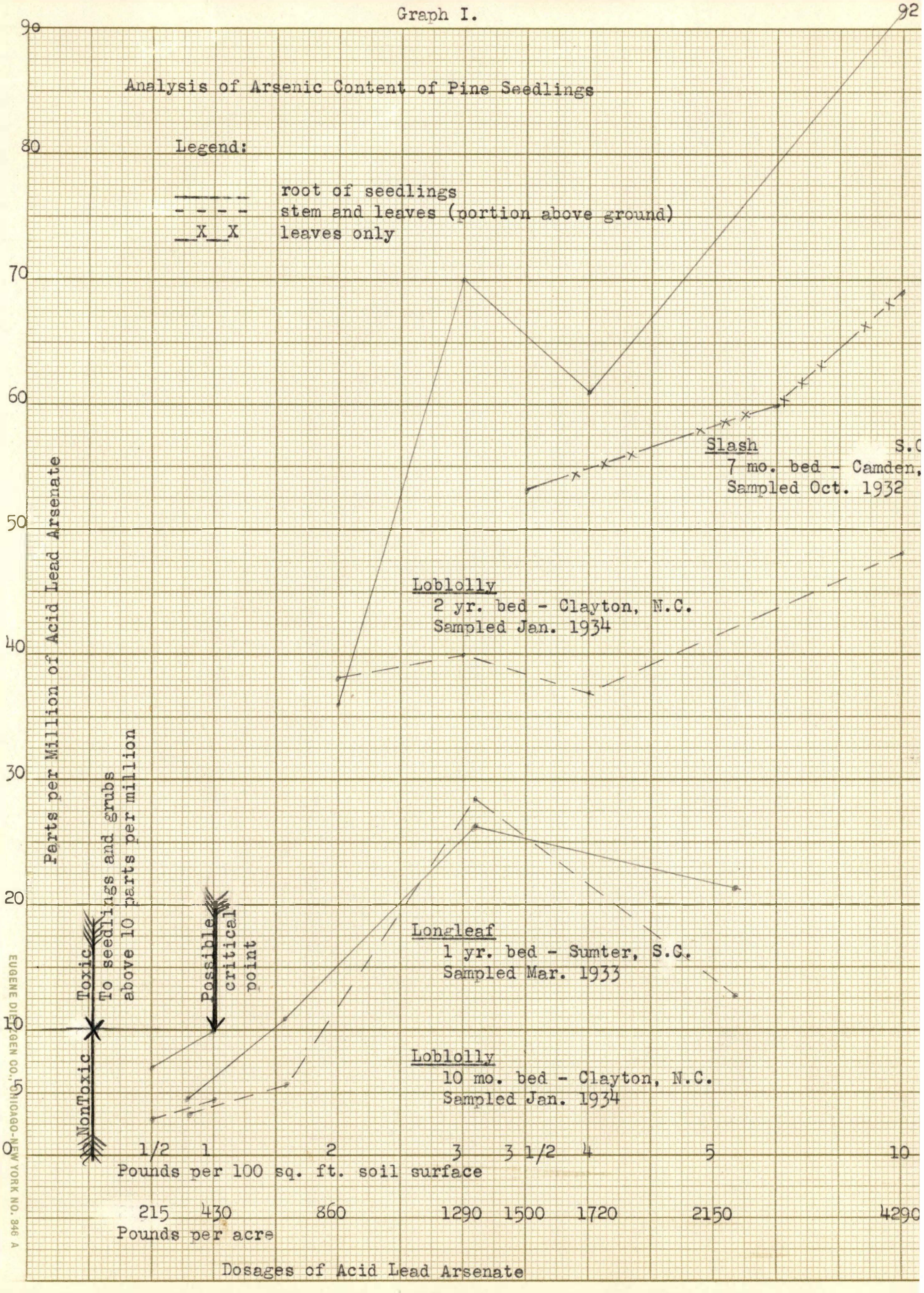
(b) With long laterals and many secondaries.

(c) " short " " few "

In the Statesburg nursery, located at Sumter, S. C., additional tests of a somewhat similar nature were conducted with arsenate of lead and the results obtained were much the same. Although there is not much data to support it, general observations indicated that there appeared to be less pronounced arsenic injury in this nursery where similar dosages and tree species had been used. This may be partly due to some difference in the soil. Such an indication of less arsenic injury here is indicated in Graph I. It will be seen that the longleaf seedlings have lower concentrations of arsenic than those of other species in the other localities, even though the dosage is similar. Such a view is only suggested in the absence of supporting data.

Dosages at the rate of 1/2, 1, 3 1/2, 5 and 10 lbs. per 100 sq. ft. of soil were applied. What appeared to be arsenic injury was noted in all of these beds except those treated with 1/2 lb. The 1 lb. bed had only a slight amount of it. Both of these lower dosages were nearly normal as far as height growth was concerned. No grub injury was noted in any of the beds until late September when there was a sudden invasion of one end of the nursery. The grubs swept through the check beds and also through those treated with 1/2 lb. of arsenic, destroying 90 percent of the latter and occasioning about a $2,000 loss altogether. Judging from these results, the dosage of 1/2 lb. per 100 sq. ft (215 lbs per acre) is not sufficiently toxic to prevent white grub attack. This ties in with the results obtained at the Clayton Nursery where seedlings, transplanted in a box treated with arsenic at this rate, were also

Graph I.



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injured by white grubs liberated in the same. Further, dosages of 2 lbs. per/100 sq. ft. (860 lbs. per acre) and above are too toxic for plant growth. Thus, the only possibility of arsenic being used alone at all is when applied in a dosage of about 1 lb. per 100 sq. ft. or 430 lbs. per acre.

The 1933 Tests

During 1933, tests were continued with acid lead arsenate for the following reasons:

(1) To determine the possibilities of safely using a dosage of 430 lbs.per acre (1 lb. per 100 sq. ft.).

(2) To determine the minimum dosage toxic to the seedlings, and

(3) To determine the length of period that the arsenic remained in the soil in a form toxic to both the grubs and seedlings.

At the Clayton nursery during early March 1933 two beds (522 sq. ft. each) were established treating one with 215 lbs. per acre, the other with 430 lbs. Loblolly pine was used in both cases and soil was used that had no arsenical in it up to that time.

An examination of these beds on January 9, 1934, revealed that the 430 lb. bed had not quite attained the height growth of the checks, but otherwise were in good condition and with compact beds. The 215 lb. bed apparently equalled that of the check in every way. There was practically no grub damage in either bed.

Further work at this nursery consisted of replanting those beds which were treated the previous year at the rate of 2, 3, 4 and 10 lbs.

per 100 sq. ft. (860 lbs. - 4,290 per acre). The shortleaf beds of 1932 were replanted to loblolly, the loblolly beds to slash, and the longleaf beds to shortleaf pine. This shifting about apparently was mainly for convenience in planting up certain parts of the nursery.

A general examination of these beds in January 1934 indicated that even after the second year there were marked evidences of stunting of growth due to the arsenic which had remained in the soil. A considerable portion of the seedlings had died after they had attained a height of 2" - 6". The toxic effects of the chemical were in proportion to dosage. However, it was noted that the longleaf seedlings were less affected than the other two species. In general, very little grub damage was experienced in the nursery during the season 1933.

Samples were removed from these beds, as well as those treated during 1932, and an analysis was made of the entire plant. The roots were analyzed separately from the rest of the plant. The results of this test will be discussed below presently. Photographs were also taken of these seedlings before being analyzed for comparison of height growth. (See fig. 1). From this figure it is evident that a marked stunting has taken place which varies with dosage.

At the Camden nursery, in addition to replanting the 1932 treated beds, other tests were conducted to determine the toxic limit of arsenic to the seedlings. For this purpose dosages of 1 lb., 1/2 lb., 1/8 lb. and 1/16 lb. were used in untreated soil. Two series were arranged, one where the beds were enclosed with fine wire to prevent possible grub

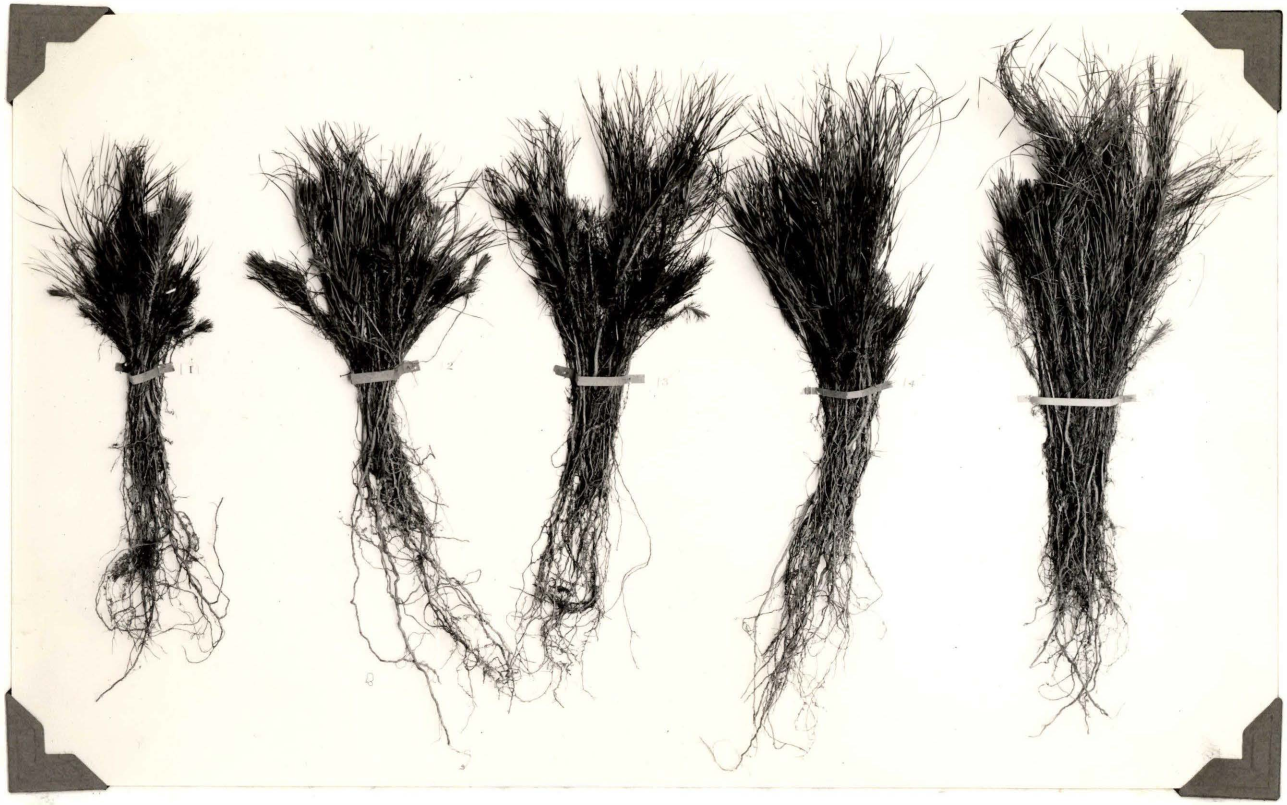

Fig. 1. Loblolly pine seedlings removed from beds treated with varying dosages of acid lead arsenate and checks. Each group contains approximately 25 seedlings. Groups 1-4 were removed in January, 1934, from beds treated in March, 1932, with the following dosages per acre respectively: 4290 lbs, 1720 lbs., 1290 lbs. and 860 lbs. This represents the following dosages per experimental bed of 100 sq. ft.: 10 lbs, 4 lbs, 3 lbs, and 2 lbs. Group 5 is an untreated check. Note stunting effect in relation to both height, growth, and root development resulting from increased dosages of arsenic.

injury, the other without it to note the effectiveness of such dosages on the grubs.

These beds were prepared in April. Unfortunately a period of dry weather followed the sowing of the seeds and so interfered with their germination that the tests had to be abandoned.

An examination of the 1932 beds, replanted in March 1933, revealed even greater arsenic injury than occurred the first season. Very few seedlings grew to any height and represented a loss of the entire beds as far as merchantable stock was concerned.

On a portion of the 10 lb. bed (4,290 lbs. per acre) a cover crop of Cotelaria (a legume) was grown during the season and apparently without any appreciable amount of injury. The portion of the plant above ground appeared normal, the root system possibly was slightly under developed, but it was necessary to compare these plants very closely with checks to detect a difference. This is of interest since other leguminous plants, like cowpeas, cannot be grown on certain soils, so as to produce a normal crop, even when such small quantities as 20-50 lbs. per annum are applied for two or three years in succession.

Analyses of the Seedlings for Arsenic Content

In view of the foregoing discussion, it would appear logical that if arsenic is as important a factor as suggested a chemical analysis of the seedlings should reveal a high poison content.

To determine this analyses were run at three different times, namely (1) October 1932 when slash pine needles were removed from seedlings in 7-month old beds, (2) March 1933 when entire seedlings of longleaf pine were taken from 1-year old beds for analysis of the arsenic content of the root and remaining portion of the plant separately, and (3) in January 1934 when loblolly pine seedlings were removed from two-year old beds for an analysis similar to (2). In addition to this other seedlings were removed from 10-month old loblolly beds established in March 1933. All of the above analyses were made to determine the quantity of the arsenic present in terms of parts per million.

The findings are presented in Graph I. It will be noted that the root contains a considerably higher concentration of arsenic than the stem as might be expected. Also that dosages of 1 lb. or less per 100 sq. ft. (430 lbs. per acre) contain 10 parts or less per million of arsenic. Where dosages of 2 lbs. or more per 100 sq. ft. are used the quantity of arsenic increases rapidly from 15 to 92 parts per million. Since the above experiments indicate that 1 lb. per 100 sq. ft. is about the toxic limit for both plants and insects, it may be assumed that this dosage is approaching the critical point for both. Thus, if it is permissible to assume this, seedlings cannot tolerate more than 10 parts of arsenic per million and quantities less than that are not toxic to the grubs.

A review of the work done recently by Albert and Paden[5] of the Soils Dept. of Clemson College indicates that, in tests where moderate dosages of 50 to 100 lbs. of calcium arsenate dust per acre are applied to light sandy soils of the Coastal Plain for a period of several years, subsequent damage will result when cover crops such as cowpeas and oats are planted subsequent to treatment. Further, that these crops cannot tolerate dosages much in excess of 8 parts per million which approaches quite closely the results suggested above in the case of the pine seedlings.

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[5] Albert, W. B. and Paden, W. R. (S. C. Expt. Sta.) Calcium arsenate and unproductiveness in certain soils. Science, June 5, 1931, Vol. 73, no. 1901, p. 622.

Other work done by Dr. Tom of the Bureau of Plant Industry suggests the possibility that certain arsenic fungi like Penicillium brevicaule can, under laboratory conditions at least, break down arsenates, reducing them to the more toxic compounds. For instance in the acid soils of the Coastal Plain it has been determined that a concentration of .1% of arsenic furnishes an attractive media for the development of this fungus. On the basis of 100 lbs. of arsenic per acre, applied to the top 6" of soil, there would be represented a concentration of .005% (100: 2,000,000 lbs.). Where 1,500 lbs. of arsenic is applied per acre the concentration would be .075% which closely approaches the optimum for Penicillium. A dosage of 4,290 lbs. per acre (10 lbs. per 100 sq. ft.) would raise the concentration approximately to .225% of arsenic. Thus it can be seen that it is within the realm of possibility that high dosages of this chemical tend to create conditions which might make certain arsenic fungi an important factor in causing injury to plant growth by means of liberating free arsenic.

These investigators also found that certain red clay soils which contain considerable iron and manganese can take care of relatively large amounts of arsenates, in some cases up to several thousand pounds per acre, without any injury to succeeding crops. This being the case it should be beneficial to apply to the arsenic treated beds in the nursery such chemicals as ferrous sulphate and hydrated lime to restore the soil to productivity so that seedlings can be grown without being injured by arsenic. Such procedure is planned for the coming season.

Plans for 1934

Briefly, the plans for the coming season are as follows:

(1) To continue replanting the 1932 treated beds to determine how long the arsenic will remain in the soil in such quantities as to be toxic to the seedlings and grubs.

(2) To determine the effectiveness of adding ferrous sulphate and hydrated lime to the soil to restore its productivity and still be toxic to white grubs.

(3) To find chemicals which can be used as substitutes for the arsenate of lead. The following are to be tried: (1) Croyolite, (2) Derris powder containing 4% rotenone, (3) Barium fluosilicate.

(4) To determine the effectiveness of the following chemicals for remedial purposes: (1) Naphthalene, (2) Calcium carbide.

(5) To make such life history studies as time will permit; especially to determine if it is possible for the grubs to cause injury by the end of the first season.

Summary and Conclusions

1. Studies for the control of white grubs in forest nurseries have been in progress since the spring of 1932.

2. Many species of Phyllophaga are apparently present in the Coastal Plain in the region of the nurseries being investigated, that are injurious to pine seedlings.

3. There are probably several forms whose life cycle is less than three years. There appears to be a considerable overlapping of generations.

4. Activity of the grubs appears to be influenced by climatic conditions, being less active during dry weather except in instances directly following heavy showers.

5. Manure beetles apparently are not injurious to seedlings.

6. Carbon disulphide is effective in controlling white grubs when applied at the rate of 1 1/2 oz. per sq. yd.

7. 50% disulphide emulsion is equally as effective and more easily applied than the undiluted product. Dosages of 1 qt. to 50 gallons of water, applying 3 pts. per sq. ft. of the diluted emulsion, were found to give satisfactory results.

8. Sodium cyanide, applied at the rate of 1 lb. to 75 gallons of water by flooding the soil, is sufficiently toxic to kill both grubs and seedlings when applied to light sandy soils.

9. Acid lead arsenate, applied at the rate of 860 lbs. per acre and above, is toxic to both pine seedlings and grubs when grown in light grey sandy acid soils of the Coastal Plain.

10. Dosages of 215 lbs. of arsenate of lead per acre are apparently non-toxic to both the seedlings and grubs.

11. Dosages of around 400 lbs. per acre appear to be effective against the grubs and relatively safe to use in the seed beds.

12. Shortleaf pine appears to be less tolerant to arsenic than loblolly, slash and longleaf. Longleaf pine seedlings appear to outgrow initial arsenic injury more easily than the other species.

13. Acid lead arsenate remains in light sandy acid soils for a period of at least two years in sufficient quantities to cause injury to seedlings where relatively heavy dosages are used.

14. If current tests do not reveal that arsenic can be used alone safely or with other chemicals, new poisons should be found which can be used as a substitute.

April 9, 1934